NITRIDE SEMICONDUCTOR DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2006-286332 filed on Oct. 20, 2006 in Japan, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a nitride semiconductor device.

[0004] 2. Related Art

[0005] In a power semiconductor device such as a switching element or a high frequency power semiconductor device, it is effective to use a material having a high critical electric field and consequently a nitride semiconductor material having high critical electric field strength is used.

[0006] As for a conventional nitride semiconductor device using a nitride semiconductor material, a first reference art is known. According to the first reference art, a carrier transit layer formed of an $Al_XGa_{1-X}N$ ($0 \leqq X<1$) film and a barrier layer formed of an $Al_YGa_{1-Y}N$ ($0<Y \leqq 1$, $X<Y$) film are stacked in order, a gate electrode is formed near a central part on the surface of the barrier layer having a uniform thickness, and a source electrode and a drain electrode are formed in substantially symmetric positions with the gate electrode between.

[0007] The AlN film is smaller in lattice constant than the GaN film. When the Al composition ratio of the barrier layer is greater than the Al composition ratio of the carrier transit layer, therefore, the lattice constant of the barrier layer becomes smaller than the lattice constant of the carrier transit layer and a strain is caused in the barrier layer. In the nitride semiconductor, polarization charges are generated in the barrier layer by piezo polarization and spontaneous polarization resulting from the strain in the barrier layer. And two-dimensional electron gas is formed at an interface between the carrier transit layer and the barrier layer by the polarization charges generated at this time.

[0008] For example, when a GaN film having Al composition ratio X=0 is used for the carrier transit layer and an $Al_YGa_{1-Y}N$ film is used for the barrier layer, a carrier density n_s of the two-dimensional electron system is given by the following equation (1) with respect to a film thickness d_1 [Å] (see, for example, J. R Ibbetson et al., "Polarization effects, surface states, and the source of electrons in AlGaN/GaN heterostructure field effect transistors," Applied Physics Letters, 10 Jul. 2000, Vol. 77, No. 2, PP. 250-252).

$$n_s=\sigma_{PZ}\times(1-T_C/d_1)\ [\mathrm{cm}^{-2}] \tag{1}$$

[0009] Here, σ_{PZ} is a charge density of polarization charges generated in the barrier layer, and d_1 is a film thickness of the barrier layer under the gate electrode. T_C is a critical film thickness of the barrier layer at which carriers are generated. This critical film thickness T_C is given by the following equation (2), and has dependence upon Al composition ratio.

$$T_C=16.4\times(1-1.27\times Y)/Y[\text{Å}] \tag{2}$$

[0010] Furthermore, a second reference art is known. According to the second reference art, a recess structure is formed by removing a part of the barrier layer in order to reduce the contact resistance in the source electrode/drain electrode in the nitride semiconductor device or the gallium arsenide semiconductor device (see, for example, JP-A 2001-274375 (KOKAI), and JP-A 2004-22774 (KOKAI)). A hetero junction field effect transistor (hereafter referred to as HJFET) described in JP-A No. 2001-274375 has a structure obtained by stacking an undoped nitride aluminum (AlN) buffer layer, an undoped GaN channel layer, an n-type AlGaN electron supply layer, a Si single atom layer and an n-type GaN cap layer are stacked on a sapphire substrate in order, removing the whole of the n-type GaN cap layer and the Si single atom layer and a part of the n-type AlGaN electron supply layer in a position where the gate electrode is formed, thereby forming a recess structure, forming a gate electrode in this recess structure, and forming a source electrode/drain electrode on the n-type GaN cap layer having the gate electrode between. In this nitride semiconductor device, the contact resistance of the source electrode/drain electrode is lowered by providing the GaN cap layer between the source electrode/drain electrode and the n-type barrier layer.

[0011] A HJFET described in JP-A 2004-22774 (KOKAI) has a structure obtained by stacking a buffer layer formed of a semiconductor layer, a GaN channel layer, an AlGaN electron supply layer, an n-type GaN layer and an AlGaN layer in order on a substrate of sapphire or the like, removing the whole of the AlGaN layer and the n-type GaN layer and a part of the AlGaN electron supply layer in a position where the gate electrode is formed, thereby forming a recess structure, forming a gate electrode on the AlGaN electron supply layer in this recess structure, and forming a source electrode/drain electrode on the topmost AlGaN layer having the gate electrode between. In this nitride semiconductor device, the contact resistance of the source electrode/drain electrode is lowered by providing the AlGaN layer and the n-type GaN layer between the source electrode/drain electrode and the barrier layer.

[0012] In the nitride semiconductor devices described in JP-A 2001-274375 (KOKAI), and JP-A 2004-22774 (KOKAI), the AlGaN electron supply layer corresponds to the barrier layer and the GaN channel layer underlying the AlGaN electron supply layer corresponds to the carrier transit layer. As described with reference to the first reference art, therefore, polarization charges are generated in the barrier layer and two-dimensional electron gas is formed at an interface between the carrier transit layer and the barrier layer. However, the carrier density of the two-dimensional electron system under the gate electrode in the nitride semiconductor device having a recess structure depends upon the Al composition ratio Y of the barrier layer and the thickness of the barrier layer under the gate electrode.

[0013] A third reference art using the $In_YAl_ZGa_{1-Y-Z}N$ film as the contact layer in the nitride semiconductor device is known (see, for example, "IEEE TRANSACTIONS ON ELECTRON DEVICE," Vol. 52, No. 10, OCTOBER, 2005, p. 2124). According to "IEEE TRANSACTIONS ON ELECTRON DEVICE," Vol. 52, No. 10, OCTOBER, 2005, p. 2124, a contact layer having a thick film thickness can be formed because the $In_YAl_ZGa_{1-Y-Z}N$ film makes lattice matching to a GaN film when the relation $Z=4.66\times Y$ is